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Near-Zero NOx Gas Turbine Combustion

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Outline

- Program structure
- Project goals
- Program milestones and schedule
- Technical results and current activities
- Key technical hurdles and plans to overcome
- Project risk
- Other low NOx technology efforts
- Impact on DER

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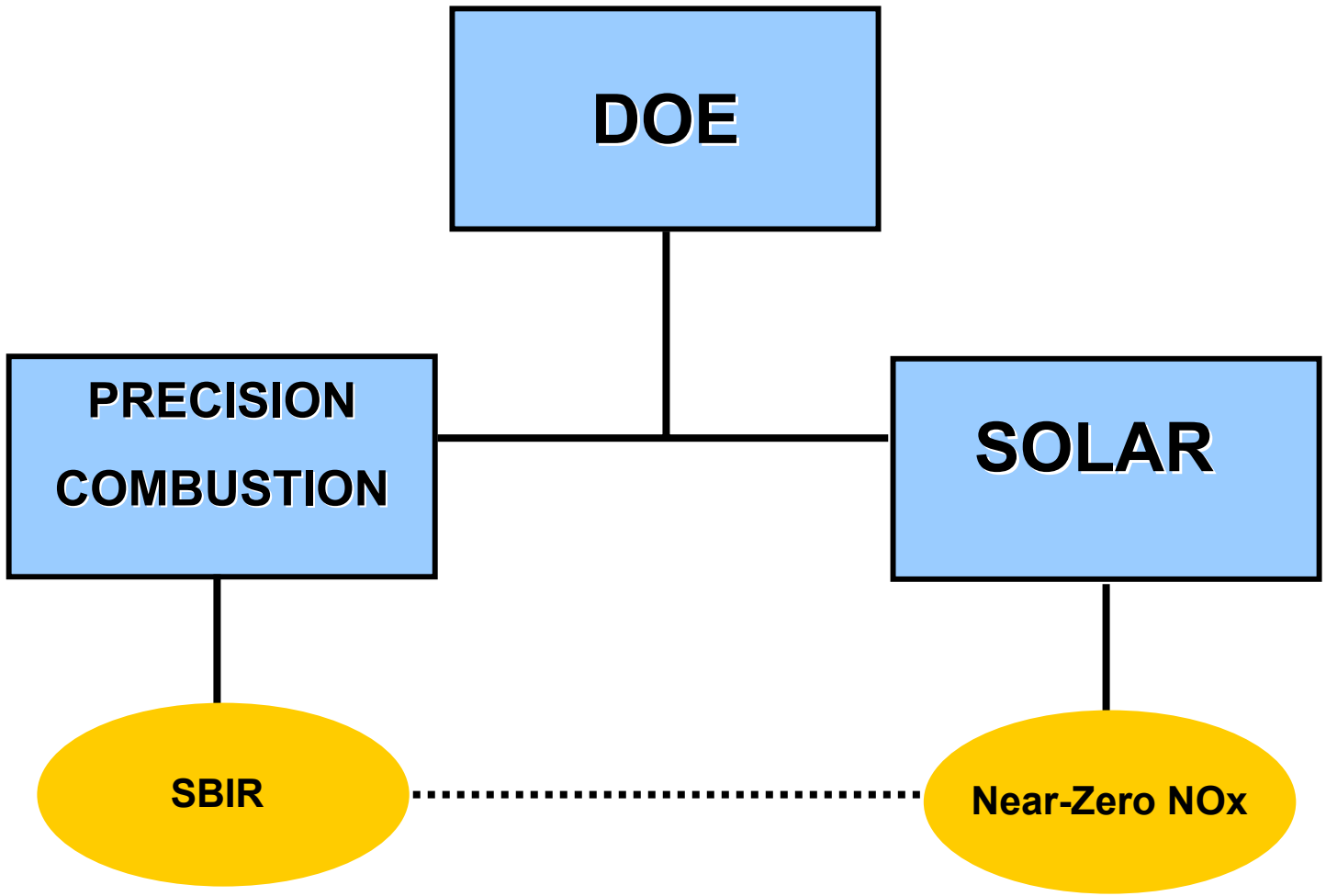
Program Structure



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The Development Team

- **Program Sponsor**
  - **U.S. Department of Energy (DOE)**
    Office of Distributed Energy, Washington, DC
    - **Debbie Haught, Merrill Smith**

- **DOE Project Management**
  - **DOE Chicago Operations Office, Argonne, IL**
    - **Dale Dietzel, Steve Waslo**
  - **DOE Golden Field Office, Golden, CO**
    - **Paul Bakke**

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Program Goals

- **Assess and advance an ultra-low NOx R/L combustion system for GTs**
  - **Seeking a cost-effective alternative to SCR**
    - **Lower electricity cost**
    - **No ammonia storage/slip issues**
    - **Easier citing of GTs**

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Technical Goals

- < 2.5 ppm NOx, < 10 ppm CO, UHC
  - Natural gas
- > 8000-hour durability
- Minimum change to current engine
- Field replaceable

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Technical Milestones

- "Proof-of-concept" rig tests
  - Single PCI R/L module
- Demonstrate operability in an "engine environment"
  - Saturn engine test (1 MW)
- Develop a Gen II module design
  - Focus on Taurus 70 (7.5 MW) application
  - Rig test a single T70 module

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Long Term Milestones – Beyond Contract Effort

- Full system rig test (12 modules)
- In-house engine test
- Long-term field test
  - Document module durability

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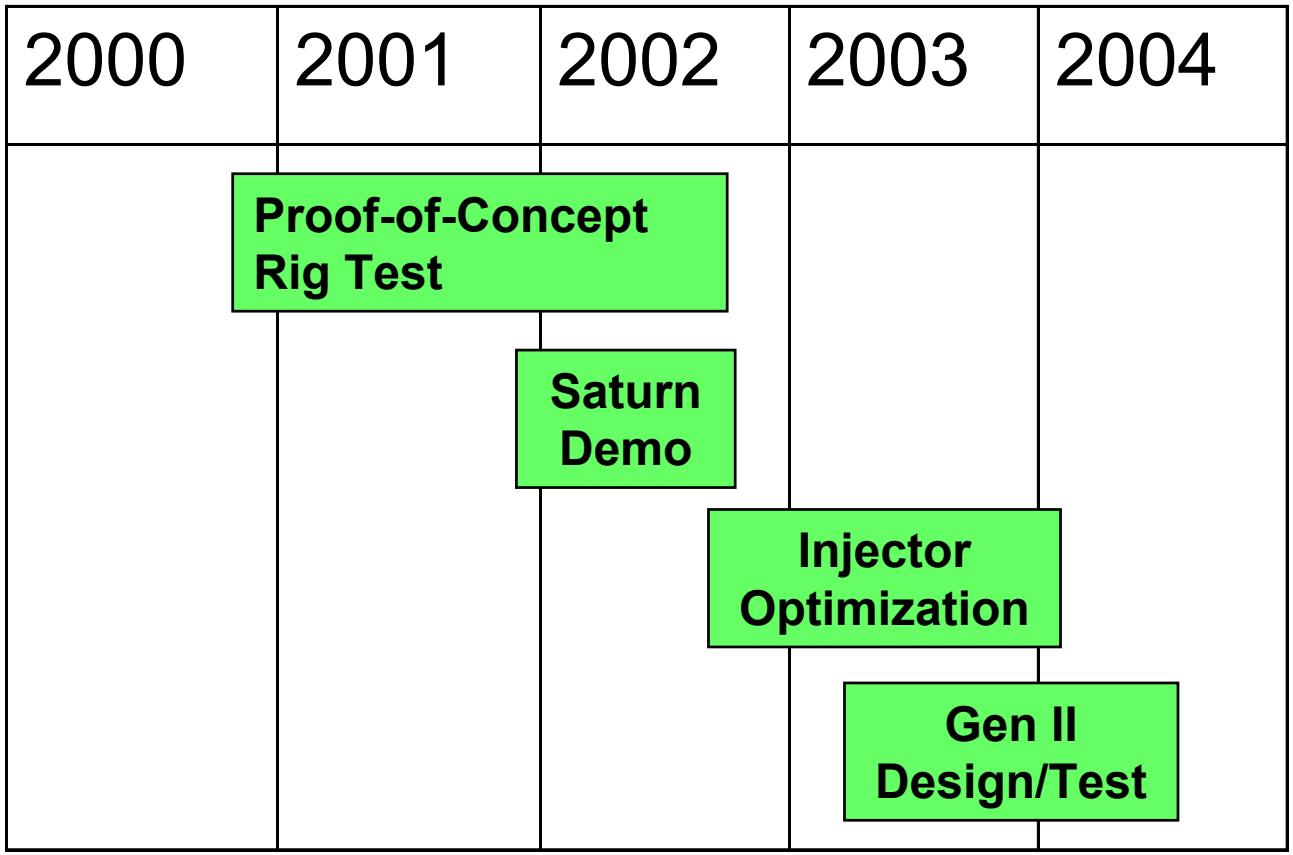
Program Schedule



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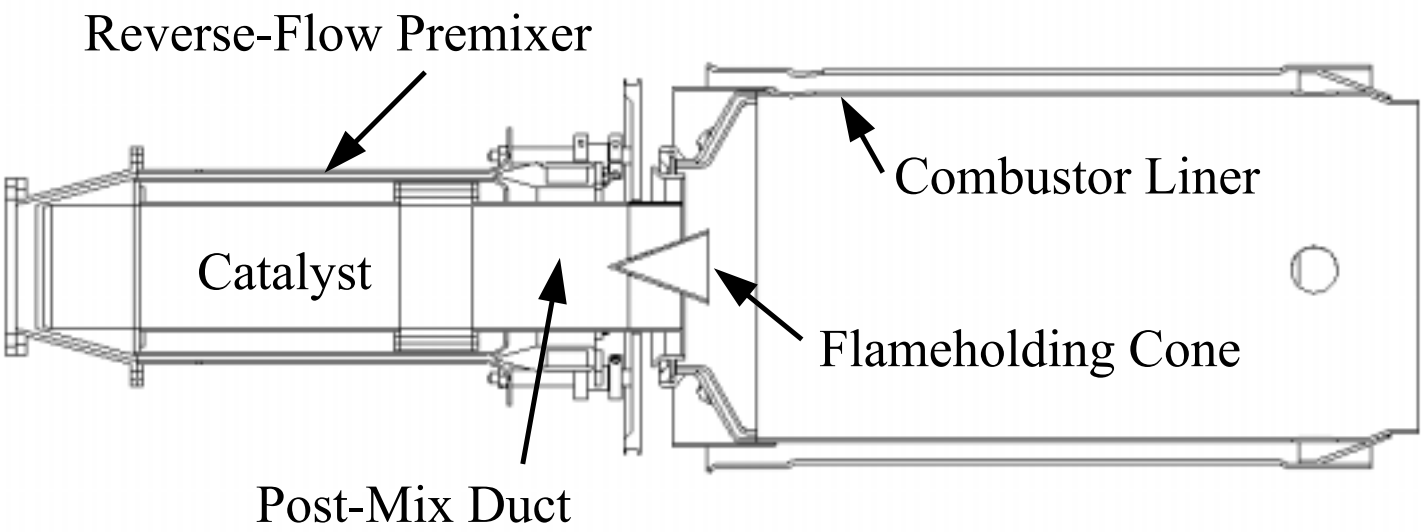
Single Burner Module Configuration



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Rich/Lean Catalytic Combustion

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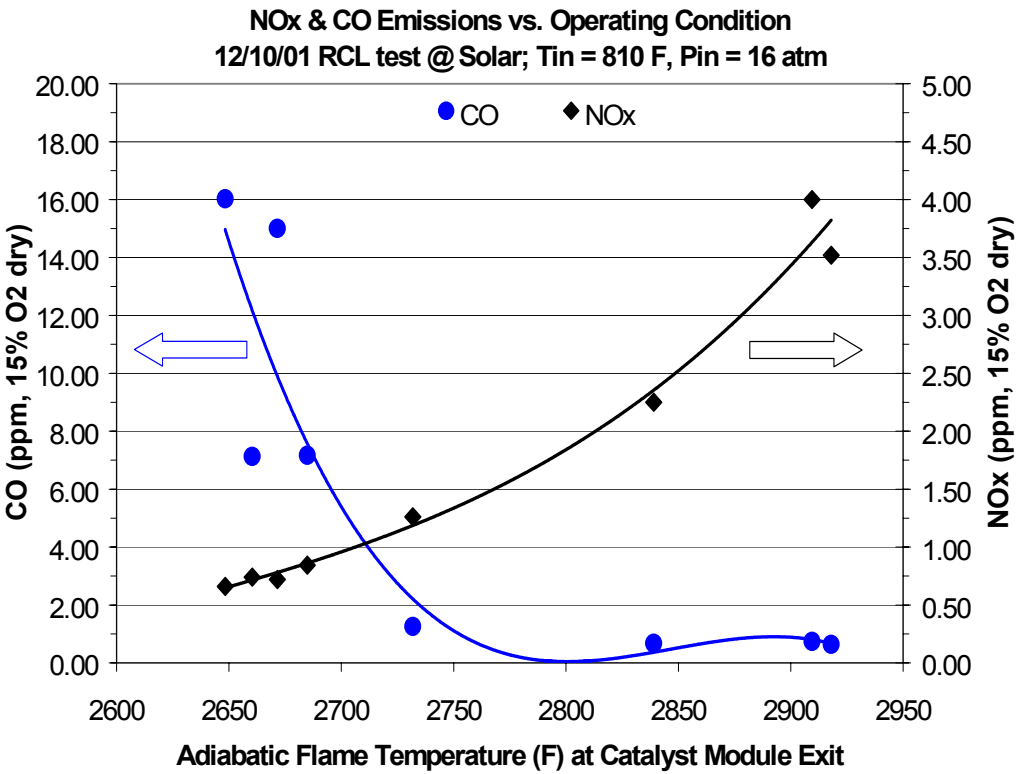
Single Injector Tests – T70 Operating Conditions



- Well-mixed, lean stable combustion achieved.
- NOx <3ppm @ 16 atmp for flame temp <2875° F.
- CO < 10 ppm for flame temp > 2660° F.
- Pressure drop < 5%
- Capable of high firing temperature operation.
- Dynamic pressure oscillations << 1/4 %
- Extremely quiet operation achieved, over wide operating range.

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Saturn Engine Test

- **Short term demonstration in an "engine environment" (1 MW)**
  - **"External can" combustion system**
  - **Four module "cluster"**
  - **Assess transient operability**

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Saturn Test Facility

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Saturn Module Construction

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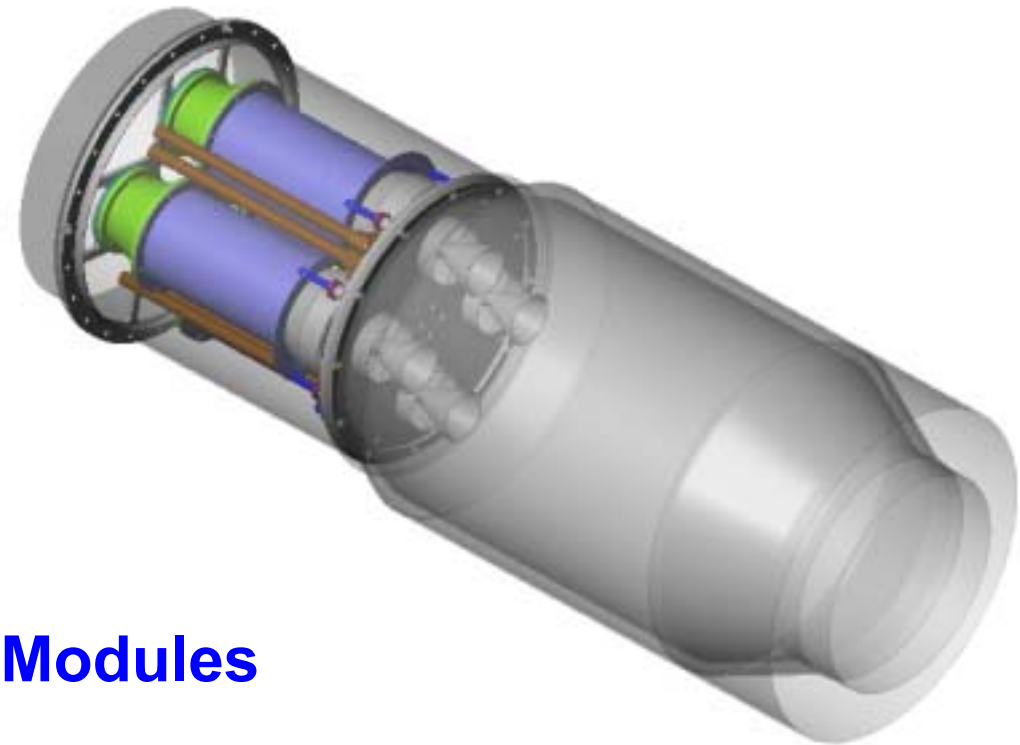
Saturn Combustor Assembly



4 R/L Modules

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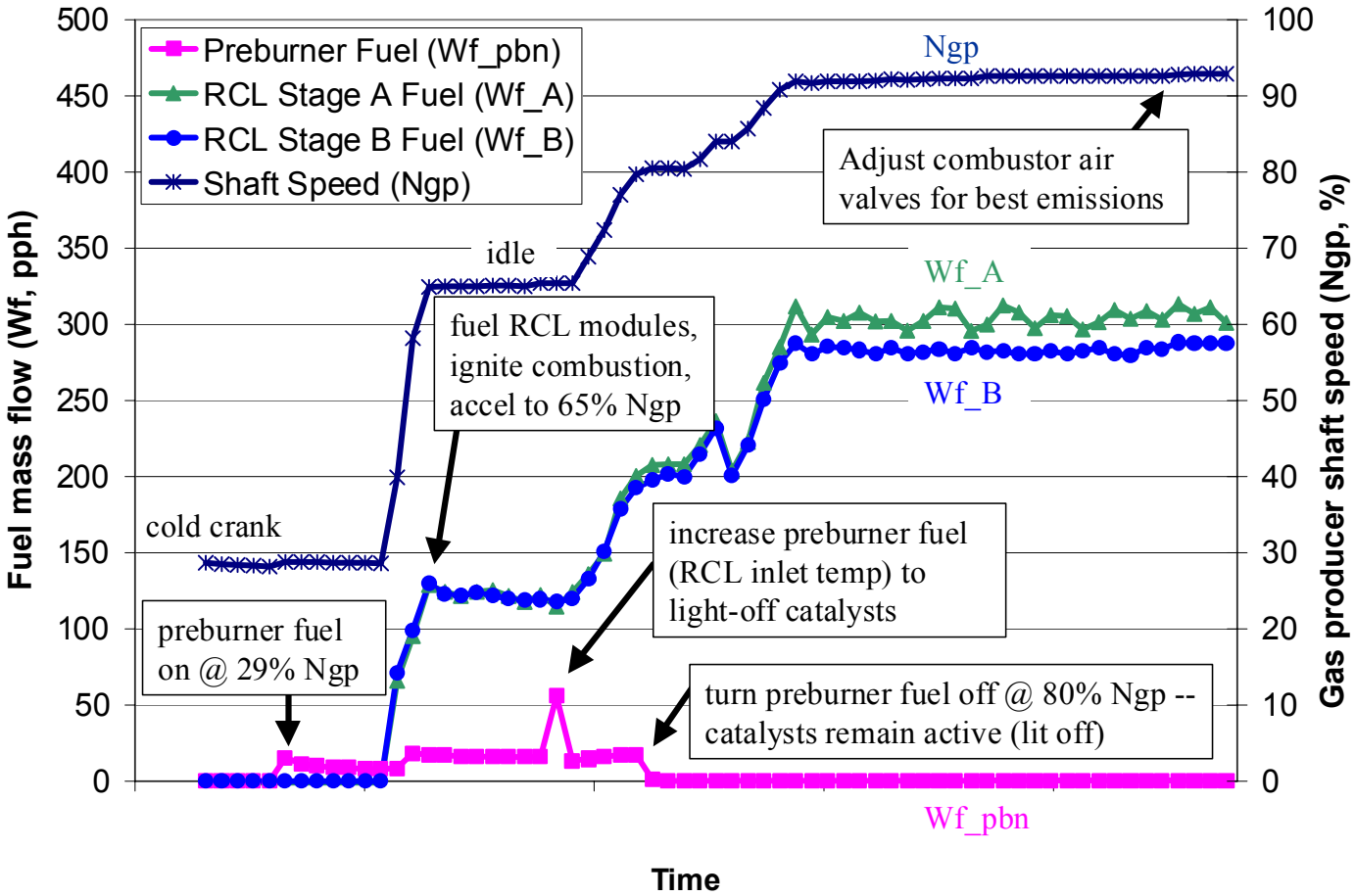
Saturn Engine Operation



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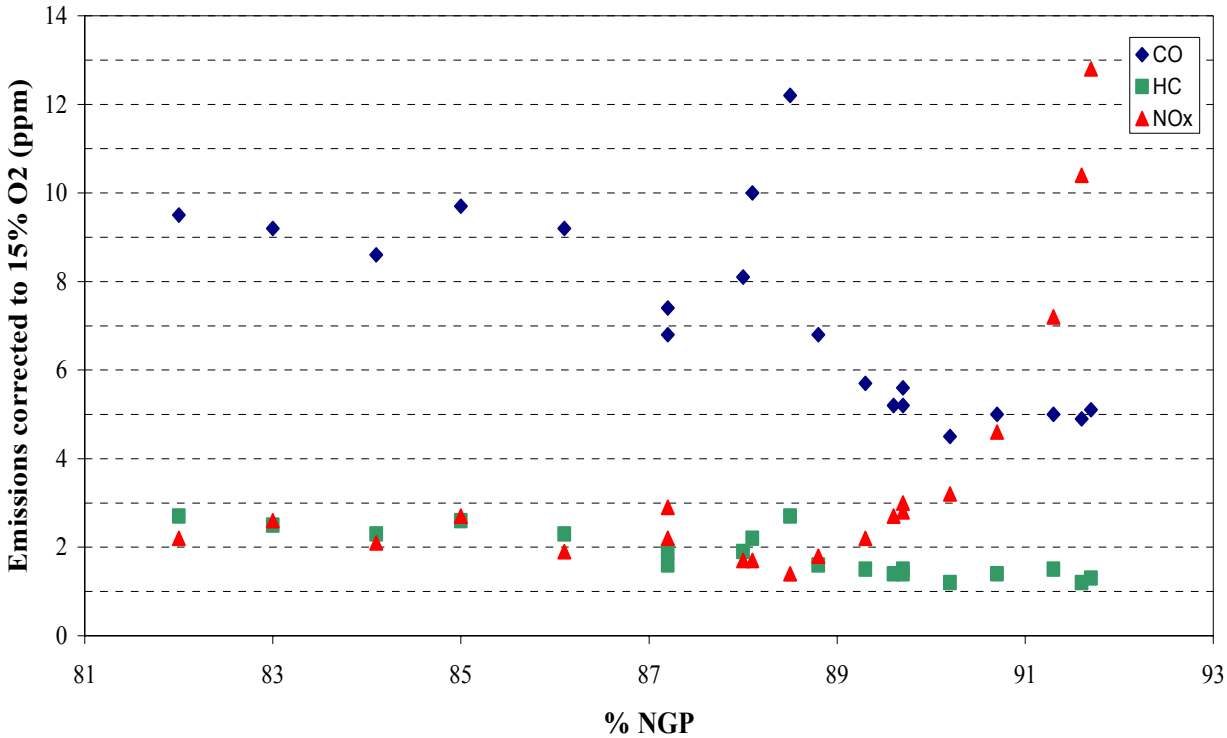
Saturn Engine Test Results



- **NOx <3ppm and CO < 10 ppm achieved between 82% NGP and 89.7% NGP**
- **Maximum speed limited by limits on scroll temperature**
- **System response to load changes and engine control very similar to SoLoNOx systems**

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Current Technical Activity

- Gen II module in design
  - Incorporates a pilot burner
  - Improved flame stabilizer
  - More robust tube bundle design
- Combustor casing and liner mods being defined

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Technical Hurdles

- Catalyst durability
- Catalytic element retention
- Catalytic reactor resonance
- Pilot performance
- CO emissions vs liner volume

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Plans to Overcome Technical Hurdles

- Complete Gen II design
- Rig tests of a single Gen II module
  - Demonstrate pilot burner performance
- Integrate activities with PCI SBIR
  - Demonstrate catalyst durability
  - Multi-burner rig and engine tests

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Project Risk

- All milestones except the last completed successfully
- Minimal technical risk involved in the successful completion of the program
- Shortfall or elimination of future funding can curtail the technical effort

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Other Low NOx Technology Efforts

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Technologies

- Surface Combustion (ALZETA)
- Lean Catalytic Combustion (CESI)
- Low Swirl Injector (LBNL/DOE)
- Catalytic Pilot for DLN (PCI)

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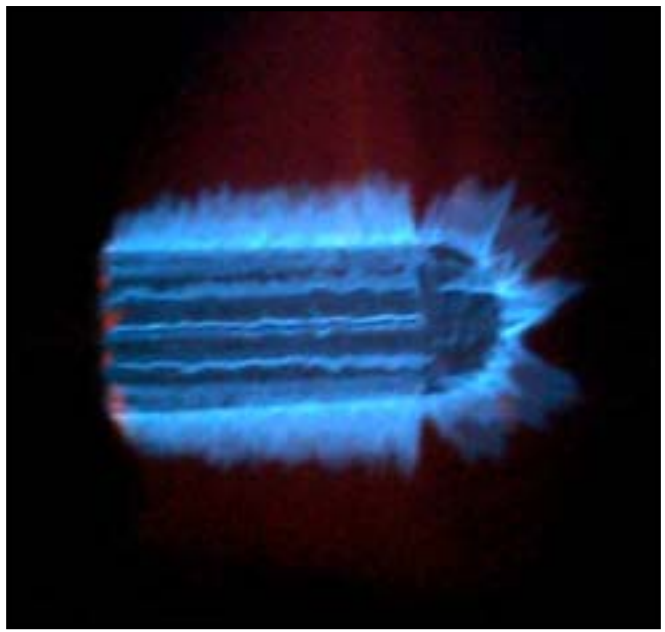
Alzeta Surface Burners



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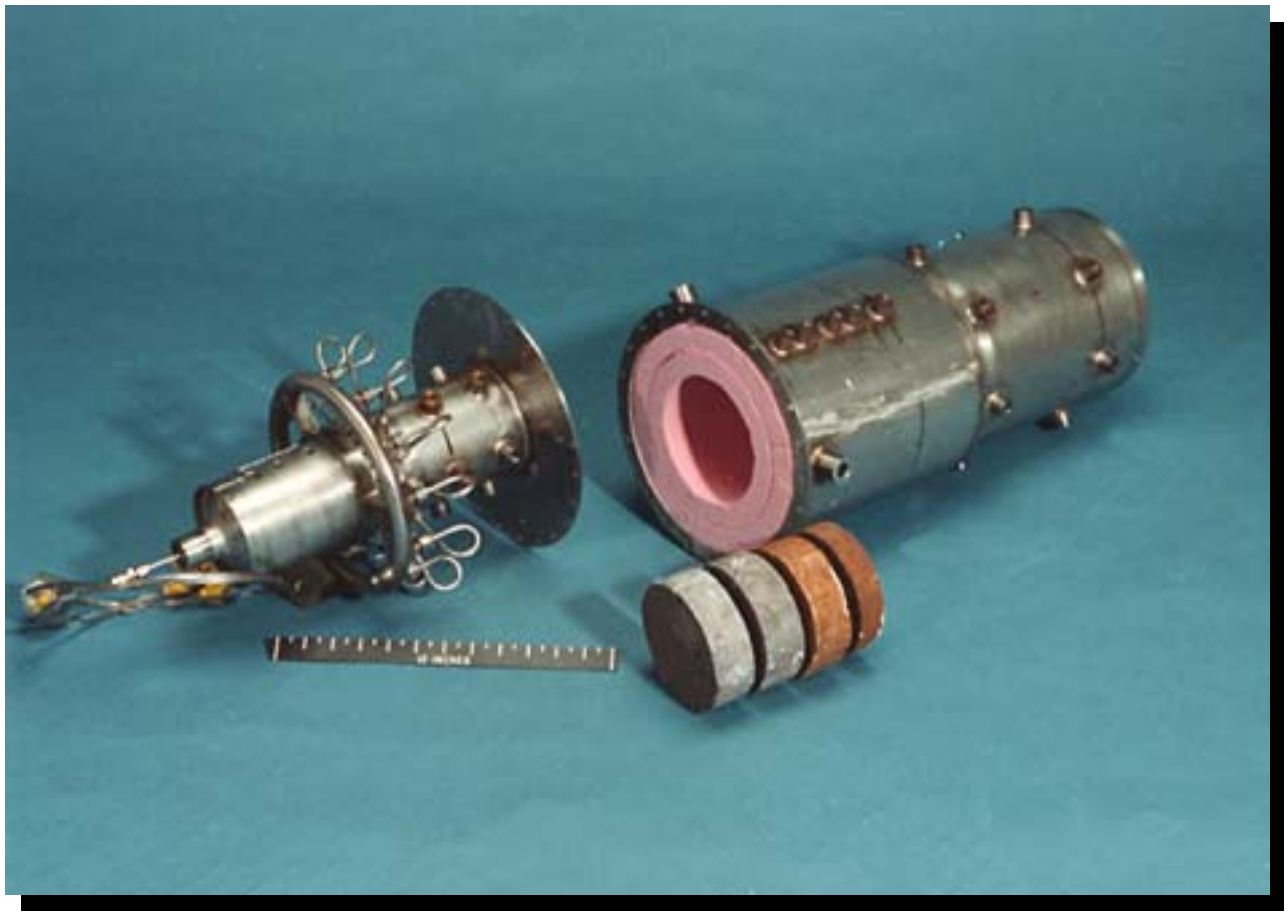
CESI Lean Catalytic Combustion



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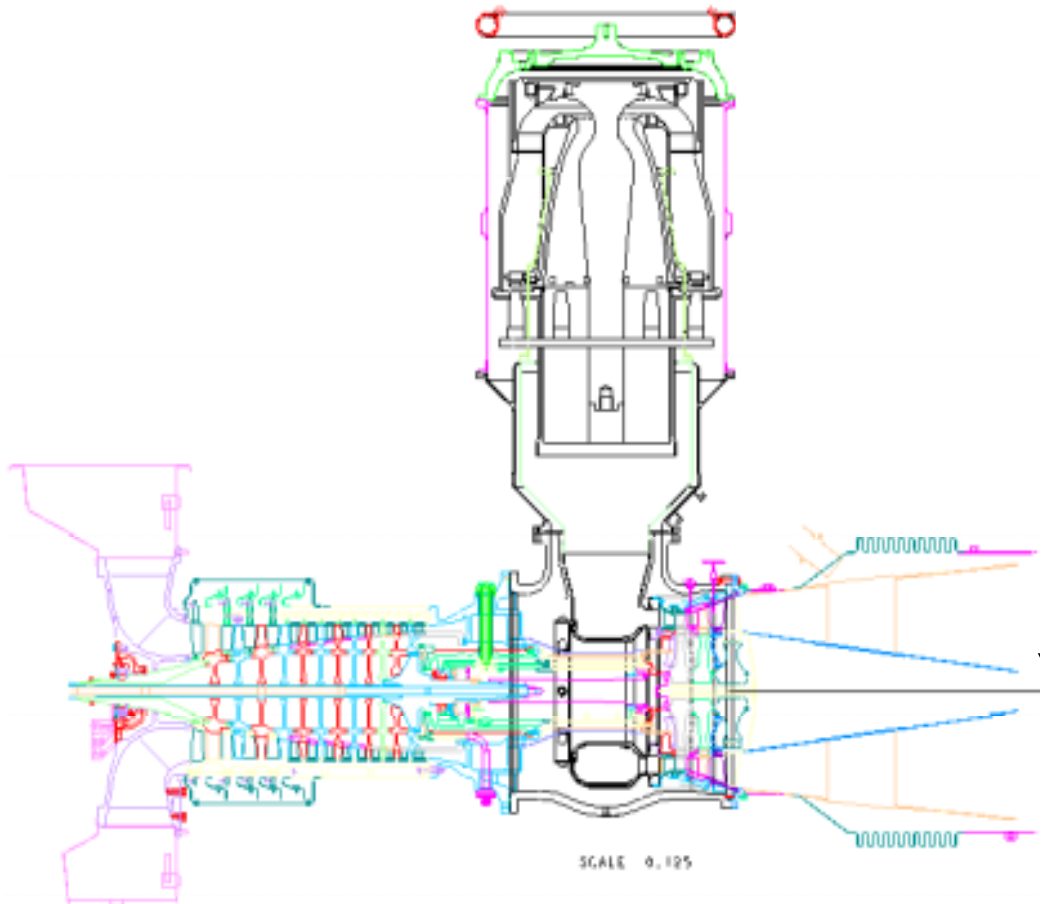
Taurus 70 Lean Catalytic Combustor Concept



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PCI R/L Catalytic Pilot

Uses PCI's Catalytic Technology in DLN Pilot

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LBNL Low Swirl Injector Development

SoLoNOx injector converted to an LSI

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Impact on DER

- **Program goals directly support DER's vision**
  - **Cleaner, smaller and more efficient units of power generation**
  - **Opportunities for greater local control of electricity delivery and consumption**
  - **Enable more efficient utilization of waste heat in combined heat and power (CHP) applications**
    - **Boosting efficiency and lowering emissions**